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Harvesting Cooling Effect on LPG-Fueled Vehicles for Mini Cooler: A Lab-Scale Investigation

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ABSTRACT

This article presents an investigation of the actual cooling effect on a lab-scale prototype of liquified petroleum gas (LPG)-fueled vehicles. The cooling effect is obtained from heat absorption by LPG on the vaporizer. Water with a mass flow rate of 1, 2 and 3 lpm is flowed from the cooling box to the LPG evaporator and flow back to the cooling box. The car used in this study has a capacity of 1500 cc that rotates 1000, 1500, and 2000 rpm. The results showed that there was a relationship between cooling power with the increase in engine speed and mass flow rate of water that crosses the evaporator. The biggest cooling power is 378 Watts at 1000 rpm with a water mass flow rate of 3 lpm.

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1. INTRODUCTION

In the last decade, road traffic jams have become a serious problem. Traffic congestion in several cities has been reported by many researchers and study centers that have affected time loss, regional economic performance, the health of drivers and passengers, and even fatalities (Weisbrod *et al.*, 2001; Hartgen *et al.*, 2009; Levy *et al.*, 2010; Sugiyanto, 2010; Onyeneke, 2018). Meanwhile, the mobility of people is increasing for various reasons such as economic activities, distribution of goods, tourism, and employment reasons (Skeldon, 2017).This trend will worsen if the number of vehicles and mobility increases but is not balanced by the provision of reliable infrastructure by Government (Kane and Behrens, 2000; Suweda, 2016).

Therefore, the demands of comfort and complete facilities in vehicles are highly desirable by consumers which include interior features in the car. Air-conditioning system must be able to maintain humidity, temperature, air circulation, and cleanliness of the air in the cabin to provide comfort and driving health (Fiser, 2013; Szczurek and Maciejewska, 2015; Qi, 2017). In addition to air-conditioning, audio-video, and ergonomic compartments, the need for fresh drinks in the vehicle also demands comfort while driving. However, the problem arises if the driver and passenger bring fresh or cold drinks from home or buy in the market because the cold temperature will not last for a long time. Meanwhile, it is not easy to get cold water in traffic or drive on the highway. In fact, dehydration while driving is very risky to health and driving concentration. As is known, the daily water requirement for adults is more than 2 liters (Aggarwal, 2012). The loss of body fluids can be faster than normal conditions if someone is in dry air due to the influence of air conditioning or driving in the summer.

One of the prospective method is using liquified petroleum gas (LPG) (Nandiyanto *et al.*, 2016). This gas is good since it has environmental friendly chemicals compared to other type of energy source (Andika and Valentina, 2016; Laaraba and Khechekhouche, 2018). Meanwhile, in LPG vehicles available cooling potential due to phase changes from liquid to vapor in the vaporizer. The change of LPG phase from 1 MPa (liquid pressurized) to 0.2 MPa (vapor regulated) requires heat absorbed from the engine coolant which is circulated in the LPG vaporizer cavities. Thus, the coolant temperature when exiting the evaporator will be lower than when it was entering the evaporator (Price *et al.*, 2004). Seeing this phenomenon, if the fuel system is conditioned and modified, this potential can be used to provide cooling effects in the mini cooler. LPG from the fuel tank before going to the combustion system is used as a refrigerant. Heat absorption by refrigerant is transferred to water and circulated to provide a cooling effect in the mini cooler in the car.

Numerical study to predict cooling potential has been carried out in the author's previous study (Setiyo, 2016; Setiyo *et al.*, 2017a; Setiyo *et al.*, 2017b). As a result, the 2000 cc spark ignition engine was able to produce a cooling effect above 1.2 kW at 3000 rpm. Furthermore, also in 2017, an experimental study was conducted to investigate the cooling effect that can be harvested from the LPG flow modeled on the air box with an additional evaporator. However, this study uses air as a heat transfer medium and is not carried out on vehicles (Setiyo *et al.*, 2017a). Therefore, as a continuation of previous studies, this paper presents an investigation to harvest the actual cooling effect on LPG-fueled vehicles with water as a heat transfer medium circulating in the LPG evaporator.

2. MATERIALS AND METHODS

2.1. Experiment Set Up and Apparatus

This research was carried out on a 1500 cc car equipped with Tesla A-100 LPG kits. To avoid the engine from overheating, the radiator fan is connected directly to the battery without control from the water temperature sensor. During the test, all vehicle accessories are turned off, such as air conditioning, headlamps, and other accessories. The LPG evaporator is installed on the left engine chamber and tied with a standard bracket. Between the evaporator and the engine installed a heat shield made of foam coated with aluminum foil. The heat shield functions as a heat radiation barrier from the engine and the hot air from the radiator fan to LPG evaporator. A cooling box containing 4 liters of water is placed on the table. A water pump is installed between the cooling box and the evaporator to circulate water at flow rate 1, 2 and 3 liters per minutes. The car engine is turned on at 1000, 1500 and 2000 rpm for each test for 600 seconds (10 minutes).

To record the temperature data, two thermocouples are implanted in the water hose on the inlet and outlet of the evaporator by special connectors reinforced with adhesive. Then, the water temperature from the thermocouple is sent to the temperature displayer. A camera is placed right in front of the temperature displayer to capture the temperature displayed. Temperature recording is carried out for 600 seconds. Then the video recording is split into 60 frames to get temperature data per 10 seconds. The scheme of the experimental setup is presented in **Figure 1** and the photographic view of apparatus is presented in **Figure 2**.

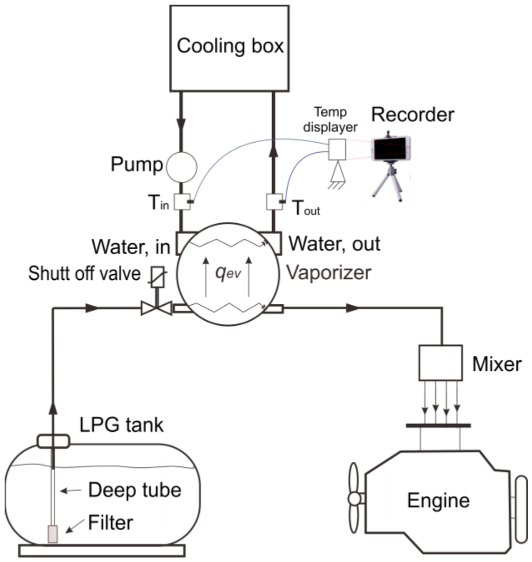

Figure 1. Scheme of experimental setup

Figure 2. Photographic view of apparatus: (1) Engine; (2) Extra fan; (3) Themocouple; (4) Cooling box; (5) Recorder; (6) Battery; (7) LPG Evaporator; and (8) Temperature displayer.

2.2. Cooling Effect Calculation

The cooling effect that can be harvested from the evaporator is calculated by **Equation (1)** as follows.

$$q = \dot{m} C_p \Delta T \tag{1}$$

Where, q is the cooling effect (kW), $\dot{m}$ is mass flow rate of water (kg/s), C_p is specific heat of water (kJ/kg °C), and ΔT is temperature difference of water when entering and exiting the evaporator (°C) obtained from a measuring instrument.

3. RESULTS AND DISCUSSION

3.1. Temperature Data

Temperature data for 600 seconds for water mass flow rates of 1 to 3 liters per minute (lpm) at 1000, 1500, and 2000 rpm are presented in **Figures 3**, **4**, and **5**, respectively. Green markers and blue markers indicate the temperature of the water when entering and exiting the evaporator; while red markers with a black trendline indicate the average temperature of both, which identifies the temperature of the water in the cooling box.

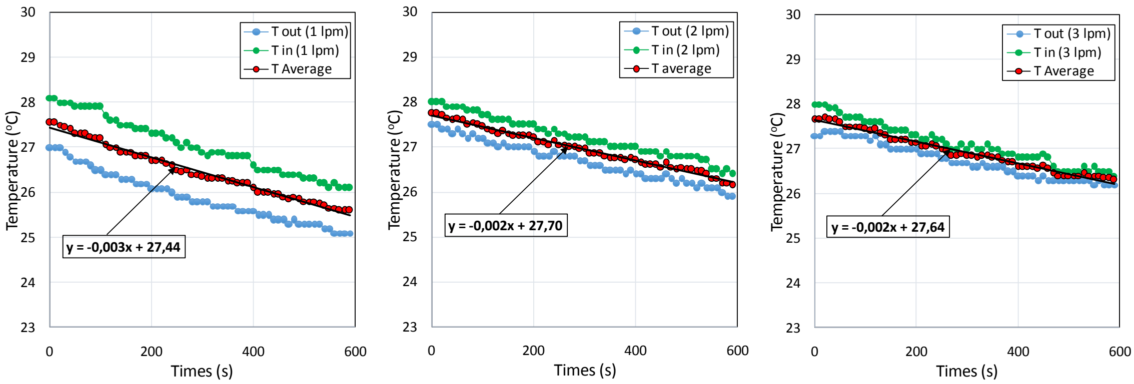

Figure 3. Temperature data for 1000 rpm, 1 to3 lpm of water flow rate

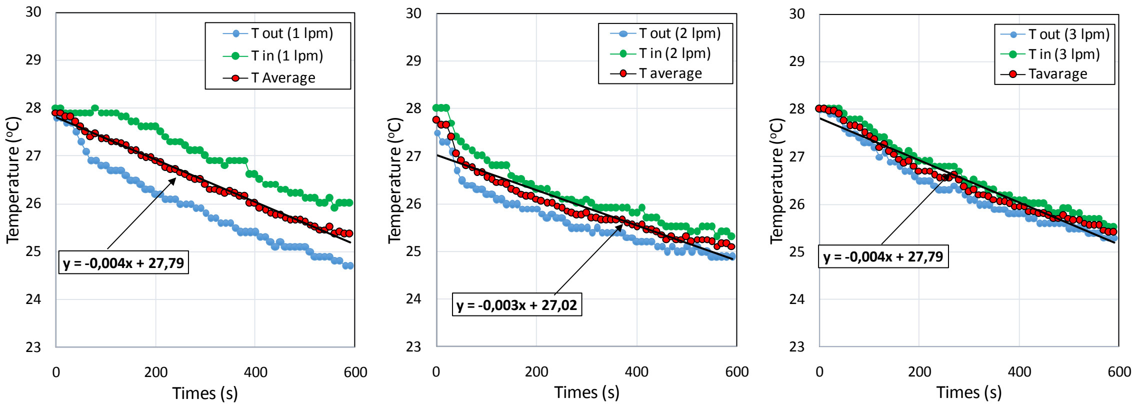

Figure 4. Temperature data for 1500 rpm, 1 to 3 lpm of water flow rate

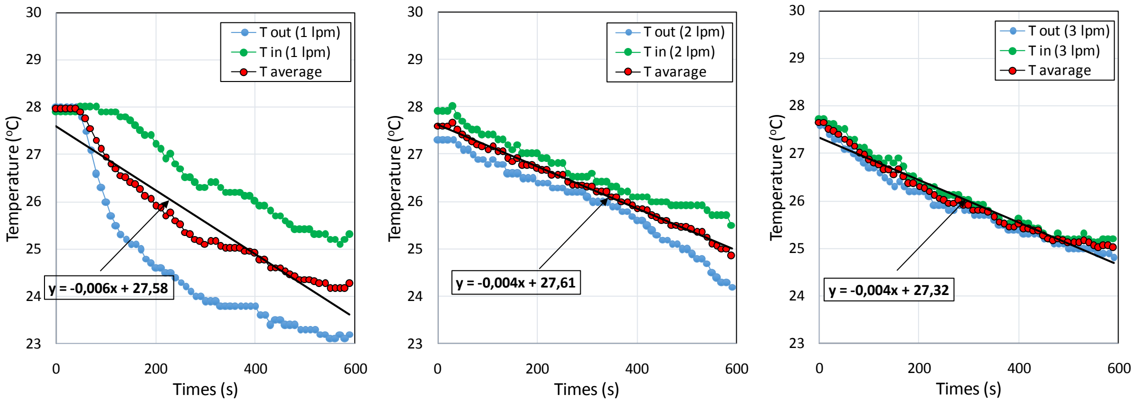

Figure 5. Temperature data for 2000 rpm, 1 to 3 lpm of water flow rate

From the test results, it appears that the higher the mass flow rate of water circulated to the evaporator, the smaller the difference in temperature generated. This trend occurs at all engine speeds of 1000, 1500 and 2000 rpm, although the temperature drop gradient occurs more steeply when engine speed is increased. At the engine speed of 2000 rpm, the trendline of decreasing water temperature produces y = -0.0067x + 27.585, which is higher than the two equations generated at 1000 and 1500 rpm. This value is predicted to be larger linearly if the engine speed is increased which indicates that the LPG flow rate is increasing. As in the previous investigation (Setiyo *et al.*, 2017a), the cooling power will increase according to the mass flow rate of LPG flowing into the engine.

3.2. Pull-down Time (t_p)

In this study, the temperature reference (T_{comf}) is fresh water obtained from the beverage cabinet in the mini market. The results of measurements by a laser thermometer GM320 series obtained a temperature of 12°C as shown in **Figure 6**.

However, water has an anomaly, which cannot be worked at temperatures below 4°C (Yasutomi, 2015). Therefore, the calculation of pull-down time also takes into account the anomaly of water. Furthermore, the estimated pull-down time (t_p) for obtaining reference temperature (T_{comf}) limited temperature (T_{lim}) for 1000, 1500 and 2000 rpm engine speed at a water mass flow rate of 1, 2, and 3 lpm is presented in **Table 1**.

From **Table 1**, it is interesting to discuss that the reference temperature (12°C) is obtained in a fairly short time, which is less than 1 hour at 2000 rpm. In fact, the vehicle generally runs from 2000 to 3000 rpm, which indicates that the reference temperature may be achieved faster. Even for vehicles with larger engine volumes, the calculation values must show better results, even though the conditions will be reversed for vehicles with smaller engine volumes.

Figure 6. Temperature reference (t_{comf})

Table 1. Pull-down time (t_P) calculation

Engine speed (rpm)	**Flow rate of water, $\dot{m}$ (lpm)**	**Equation from temperature data**	**temperature reference (T_{comf})**	**Pull-down time (t_p) T_o to T_{comf}, hour**	**Pull-down time (t_p), T_o to T_{lim}, hour**
1000	1	y = -0.0033x + 27,447	12°C	1.3	1.8
	2	y = -0.0025x + 27,701	12°C	1.7	2.5
	3	y = -0.0024x + 27,646	12°C	1.8	2.6
1500	1	y = -0.0037x + 27,025	12°C	0.9	1.4
	2	y = -0.0037x + 27,025	12°C	1.1	1.6
	3	y = -0.0044x + 27,799	12°C	0.9	1.4
2000	1	y = -0.0067x + 27,585	12°C	0.6	0.9
	2	y = -0.0044x + 27,613	12°C	0.9	1.4
	3	y = -0.0045x + 27,325	12°C	0.9	1.3

3.3 Cooling Power (W)

Cooling power is calculated by **Equation (1)**. With specific heat (C_p) of water of 4200 J/kg °C, the actual cooling power obtained is presented in **Table 2**.

In the form of graphs, the calculation of cooling effects in **Table 2** is presented in **Figure 7**. There is a relationship between cooling power with the increase in engine speed and the mass flow rate of water that crosses the evaporator. The higher the engine speed and water mass flow rate, the higher the cooling power is generated, even though it forms a different trendline.

Table 2. Cooling power (q) calculation

Engine speed (rpm)	**Mass flow rate of water, $\dot{m}$ (lpm)**	**(kg/s)**	**Specific heat of water, C_p (J/kg °C)**	**Temperature different, ΔT (°C)**	***Cooling power,* $q = \dot{m}C_p\Delta T$ (Watt)**
1000	1	0.017	4200	1.3	91
	2	0,033	4200	1.7	238
	3	0.050	4200	1.8	378
1500	1	0,017	4200	0.9	63
	2	0.033	4200	1.1	154
	3	0.050	4200	0.9	189
2000	1	0.017	4200	0.6	42
	2	0.033	4200	0.9	126
	3	0.050	4200	0.9	189

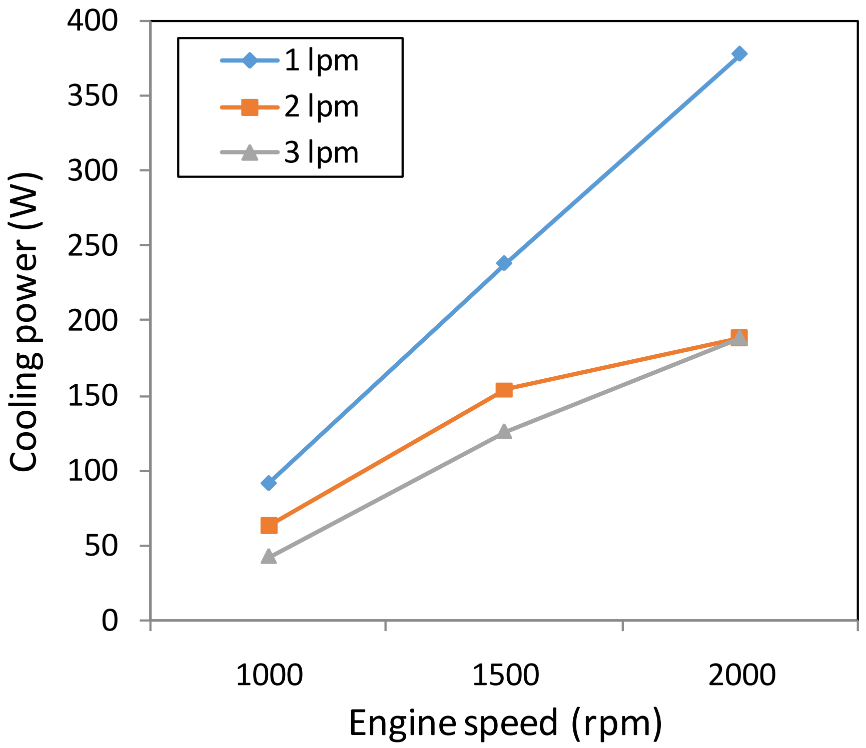

Figure 7. Trend ofcooling power (q)

4. CONCLUSION

Based on the results of the study, we found two conclusions. First, the mini-cooling box is promising to be applied to LPG-fueled vehicles because it proves to produce a cooling effect. The highest cooling effect on the 1500 cc engine is 378 Watts when the engine rotates 1000 rpm with a water mass flow rate of 3 lpm and the smallest is 42 Watts when the engine rotates 2000 rpm with a water mass flow rate of 1 lpm. Second, the higher the engine speed, the pull-down time to reach the intended temperature (12 °C) is faster. The fastest pull-down time is 0.6 hours when the engine rotates 2000 rpm with a water mass flow rate of 1 lpm and the longest pull-down time 1.8 hours when the engine rotates 1000 rpm with a water mass flow rate of 3 lpm. However, this study has a disadvantage because the LPG mass flow rate is not measured so that the heat exchange efficiency cannot be presented. Therefore, this study will be continued at a larger scale by considering the LPG mass flow rate.

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6. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the data and the paper are free of plagiarism.

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